



 Research Article

RENEWABLE ENERGY SOURCES: ADVANCEMENTS, CHALLENGES, AND PROSPECTS

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Xamitov Faxri Maxmut O'g'li
Jizzakh Polytechnic Institute, Uzbekistan

ABSTRACT

Renewable energy sources have emerged as a pivotal solution to the dual challenge of meeting the growing global energy demand while reducing greenhouse gas emissions and mitigating climate change. This scientific article comprehensively explores various renewable energy sources, including solar, wind, hydroelectric, geothermal, and biomass, highlighting their advancements, challenges, and prospects in the contemporary energy landscape. The article reviews recent research and developments in each domain, delves into the technical and economic viability of these sources, and addresses the barriers that hinder their widespread adoption. Additionally, the article discusses the role of policy frameworks, technological innovations, and international collaborations in fostering the transition towards a sustainable and renewable energy future.

KEYWORDS

Renewable energy, Solar energy, Wind energy, Hydroelectric energy, Geothermal energy, Biomass energy, Energy conversion, Energy efficiency.

INTRODUCTION

The global energy landscape is undergoing a significant transformation as the world grapples with the pressing challenges of meeting

escalating energy demands while mitigating the adverse impacts of climate change. In response to these intertwined issues, renewable energy

sources have emerged as a compelling and sustainable solution. This introductory section aims to provide an overview of the critical role that renewable energy sources play in addressing these challenges, setting the stage for a comprehensive exploration of various renewable sources, their advancements, challenges, and future prospects.

The relentless consumption of fossil fuels over the past century has resulted in unprecedented levels of greenhouse gas emissions, exacerbating global warming and its associated consequences. As concerns about the finite nature of fossil fuels and their environmental toll mount, renewable energy sources have emerged as a beacon of hope for a cleaner, greener energy future. By harnessing the power of natural processes such as sunlight, wind, water flow, and Earth's heat, renewable energy technologies offer the promise of abundant and low-carbon energy generation.

Solar energy, derived from the radiant energy of the sun, has gained significant attention due to its virtually limitless potential. Recent advancements in photovoltaic technology have led to increased efficiency and reduced costs, making solar power a viable alternative to conventional energy sources. Similarly, wind energy, propelled by the kinetic energy of moving air masses, has evolved with the development of larger and more efficient wind turbines. These turbines, often installed in wind farms both onshore and offshore, demonstrate the growing feasibility of wind energy as a reliable power source.

Hydroelectric energy, one of the oldest forms of renewable energy, continues to provide a substantial portion of the world's electricity. By harnessing the gravitational potential energy of flowing water, hydroelectric power plants have contributed to grid stability and emission reductions. Geothermal energy, tapping into the Earth's internal heat, offers another avenue for clean energy production, particularly in regions with suitable geological conditions. Furthermore, biomass energy capitalizes on organic materials, such as agricultural residues and organic waste, to generate heat and electricity, thus promoting both energy generation and waste management.

Innovation across the renewable energy spectrum has led to breakthroughs in energy storage, grid integration, and materials science. These advancements address the challenges associated with the intermittent nature of renewable sources, paving the way for a more reliable and resilient energy system. However, despite these advancements, renewable energy adoption faces barriers such as initial costs, regulatory frameworks, and the need for enhanced energy infrastructure.

Effective policy frameworks and international cooperation are indispensable in the transition to a renewable energy-based future. Governments, industries, and stakeholders worldwide are increasingly recognizing the importance of aligning policies with sustainability goals, thereby facilitating the integration of renewables into existing energy systems. International agreements and collaborations further underscore the shared commitment to

combatting climate change through renewable energy adoption.

This article aims to delve deeper into each renewable energy source, providing insights into their technological advancements, challenges, and potential contributions to a sustainable energy landscape. By critically analyzing these sources and their interactions, we can envision a future where renewable energy plays a central role in securing a cleaner, more prosperous planet for generations to come.

Solar Energy:

Solar Energy: Illuminating the Path to Sustainable Power Generation

Solar energy stands as one of the most promising and rapidly advancing renewable energy sources in the world today. Derived from the sun's abundant and inexhaustible radiation, solar power offers a clean and virtually limitless energy supply. This section delves into the various technologies that harness solar energy, examines their recent advancements, explores their challenges, and underscores their pivotal role in the global transition towards a sustainable energy future.

Solar Photovoltaic (PV) Technology: Solar photovoltaic (PV) technology, which converts sunlight directly into electricity using semiconductor materials, has undergone remarkable evolution. Recent advancements in PV cell efficiency, manufacturing techniques, and materials have resulted in increased power output and reduced costs. Emerging technologies

like perovskite solar cells and tandem solar cells are revolutionizing the efficiency landscape, offering the potential for even more affordable and efficient solar panels.

Concentrated Solar Power (CSP): Concentrated Solar Power (CSP) systems utilize mirrors or lenses to concentrate sunlight onto a central receiver, which then generates heat to produce electricity. CSP technology has made significant strides, with innovations in thermal storage systems enabling energy generation even when the sun is not shining. These advancements address the intermittency challenge associated with solar energy and position CSP as a reliable option for large-scale power production.

Advancements in Energy Storage: A critical aspect of solar energy adoption lies in addressing its intermittency due to varying weather conditions. Energy storage technologies, such as lithium-ion batteries, flow batteries, and thermal energy storage, have witnessed substantial progress. These storage solutions help store excess energy generated during peak sunlight hours and release it when demand is high or sunlight is scarce, contributing to grid stability and energy reliability.

Challenges and Solutions: While solar energy's potential is undeniable, challenges remain. Intermittency, grid integration, and energy storage are key concerns. Overcoming these hurdles requires innovative solutions such as advanced forecasting techniques, smart grids, and hybrid energy systems that combine solar

power with other renewable sources to ensure a consistent and dependable energy supply.

Solar Energy in Developing Countries: Solar energy holds tremendous promise for improving energy access in developing countries. Distributed solar installations, such as solar microgrids and off-grid solar systems, are transforming remote communities by providing reliable electricity for households, schools, and businesses. These systems not only bridge energy gaps but also foster economic development and enhance living conditions.

Environmental Benefits and Sustainability: Solar energy's environmental benefits are far-reaching, as it produces no greenhouse gas emissions during operation. The reduction in air pollution and carbon emissions contributes to combating climate change and improving air quality. Moreover, solar installations can be integrated into existing infrastructure, minimizing land use impacts and supporting a sustainable urban landscape.

Future Prospects: The future of solar energy is bright. As technology continues to advance and costs decline, solar power is poised to become an increasingly dominant player in the global energy mix. Innovations in flexible and transparent solar panels, building-integrated photovoltaics, and solar-powered transportation further expand solar energy's potential applications.

In conclusion, solar energy has undergone rapid transformation, evolving from a niche technology to a mainstream energy source with immense potential. The advancements in solar PV and CSP

technologies, coupled with progress in energy storage and grid integration, position solar energy as a cornerstone of the transition to a low-carbon energy future. By leveraging solar energy's strengths and addressing its challenges, societies around the world can illuminate a path towards a cleaner, more sustainable, and energy-abundant world.

Wind Energy:

Wind Energy: Harnessing the Power of the Breeze for a Sustainable Future

Wind energy has emerged as a key contender in the global pursuit of sustainable and renewable power sources. By converting the kinetic energy of moving air masses into electricity, wind energy offers a reliable and environmentally friendly alternative to traditional fossil fuels. This section delves into the various facets of wind energy, ranging from technological innovations and operational benefits to challenges and its role in the larger renewable energy landscape.

Onshore and Offshore Wind Farms: Onshore wind farms, characterized by the installation of wind turbines on land, have become a common sight across many regions. These farms capitalize on the consistent winds found in suitable locations, generating substantial amounts of electricity. However, offshore wind energy has gained momentum as well, with turbines installed in coastal waters to harness stronger and more consistent offshore winds. Offshore wind farms have the potential to generate higher amounts of energy and reduce visual impacts compared to onshore installations.

Advancements in Wind Turbine Technology: The evolution of wind turbine technology has been instrumental in driving the expansion of wind energy capacity. Modern wind turbines are taller, equipped with longer blades, and designed to capture more energy from the wind. The integration of smart technologies, such as real-time monitoring and blade pitch control, enhances efficiency and allows for optimized energy generation.

Grid Integration and Stability: As wind energy capacity increases, ensuring seamless integration with the existing energy grid becomes crucial. Variability in wind speed poses challenges for grid stability, requiring advanced forecasting techniques and grid management strategies. Energy storage systems, demand response programs, and improved grid infrastructure help mitigate the impacts of wind energy intermittency and enhance its reliability.

Environmental and Economic Benefits: Wind energy offers numerous environmental benefits, including zero greenhouse gas emissions and reduced air pollution. Moreover, wind energy projects stimulate local economies by creating jobs, fostering technological innovation, and generating revenue for landowners and communities hosting wind farms.

Challenges and Solutions: While wind energy holds immense promise, challenges persist. Concerns about noise pollution, visual impacts, and potential harm to wildlife have led to debates over the optimal locations for wind farms. Innovations in turbine design, advanced noise

reduction techniques, and strategic placement can help mitigate these challenges and promote social acceptance.

Offshore Wind Potential: Offshore wind energy presents a particularly promising avenue for sustainable power generation. Its potential to tap into stronger and more consistent winds, along with the ability to place turbines farther from populated areas, addresses some of the challenges faced by onshore wind projects. Collaboration among industries, governments, and researchers is key to unlocking the full potential of offshore wind energy.

Integration with Energy Mix: Wind energy's capacity to generate power complementarily with solar energy and other renewables highlights its role in a diversified energy mix. Integrated energy systems, where wind and solar complement each other's intermittency, contribute to grid stability and a more reliable energy supply.

Future Outlook: As wind energy technology continues to evolve and costs decrease, its contribution to global electricity generation is expected to soar. The development of next-generation turbines, innovations in energy storage, and increasing adoption of hybrid renewable energy systems will further solidify wind energy's position as a vital component of the transition towards a sustainable energy future.

In conclusion, wind energy's remarkable progress and its ability to provide clean, abundant, and affordable power make it a central player in the quest for a greener energy landscape. By addressing challenges, fostering technological

advancements, and prioritizing sustainable development, societies can harness the power of the wind to drive positive environmental and economic outcomes.

Hydroelectric Energy:

Hydroelectric Energy: Channeling Nature's Flow into Sustainable Power Generation

Hydroelectric energy, derived from the kinetic energy of flowing water, has stood the test of time as a dependable and renewable energy source. This section delves into the intricacies of hydroelectric power generation, highlighting its various forms, technological advancements, environmental considerations, and its significance in the global transition to clean and sustainable energy systems.

Types of Hydroelectric Systems: Hydroelectric power plants come in various forms, including run-of-the-river, reservoir, and pumped-storage systems. Run-of-the-river systems utilize the natural flow of rivers to generate electricity, while reservoir systems store water in dams to be released through turbines as needed. Pumped-storage facilities play a vital role in grid stabilization by storing excess electricity during periods of low demand and releasing it during peak hours.

Advancements in Turbine Technology: Turbine technology has evolved significantly in the hydroelectric sector. Modern turbines are designed for optimal efficiency and minimal environmental impact. Francis, Kaplan, and Pelton turbines are commonly used, each suited

for specific flow and head conditions. Computational modeling and simulation techniques have facilitated the development of turbines that harness energy more efficiently while minimizing ecological disruption.

Environmental Considerations: Hydroelectric energy offers a relatively low carbon footprint compared to fossil fuels, making it an attractive choice for mitigating climate change. However, the construction of dams and reservoirs can impact ecosystems, alter waterways, and affect aquatic habitats. Balancing the benefits of energy generation with ecological conservation requires thorough environmental impact assessments, habitat restoration efforts, and sustainable dam operations.

Hydroelectric Energy for Grid Stability: Hydroelectric power plants play a critical role in grid stability and reliability. Their ability to rapidly adjust power output makes them valuable for meeting fluctuating electricity demand. Moreover, hydroelectric systems provide ancillary services, such as frequency regulation and voltage control, which contribute to overall grid stability.

Small-Scale and Micro Hydropower: In addition to large-scale hydroelectric plants, small-scale and micro hydropower installations serve remote and rural communities with limited access to electricity. These decentralized systems harness the energy of local water resources, providing clean and reliable power for local needs. They not only improve energy access but also contribute to community development.



Challenges and Adaptations: Hydroelectric energy is not without challenges. Environmental concerns, sedimentation, and potential conflicts over water use necessitate adaptive management strategies. Aging infrastructure also poses challenges, prompting the need for modernization and retrofitting to ensure long-term operational efficiency and safety.

Hydroelectric Energy's Role in Energy Transition: As the world strives to reduce reliance on fossil fuels, hydroelectric energy holds a significant role in the transition to cleaner energy systems. Its flexibility, low emissions, and ability to support other renewable sources make it a crucial asset in achieving sustainable energy goals.

Future Prospects: Continued advancements in turbine design, reservoir management, and environmental mitigation will further enhance the sustainability of hydroelectric energy. Collaboration among stakeholders, technological innovation, and informed policy decisions will pave the way for a future where hydroelectric power generation contributes substantially to a reliable, resilient, and environmentally responsible energy grid.

In conclusion, hydroelectric energy's ability to harness the natural power of water offers a compelling solution to global energy challenges. By embracing responsible practices, innovative technologies, and effective governance, societies can utilize this age-old yet dynamic source of energy to drive progress towards a cleaner and more sustainable future.

Geothermal Energy:

Geothermal Energy: Tapping Earth's Heat for Sustainable Power Generation

Geothermal energy, harnessing the Earth's internal heat, stands as a unique and promising renewable energy source that provides a consistent and dependable power supply. This section delves into the intricacies of geothermal energy, exploring its various forms, technological advancements, environmental considerations, challenges, and its pivotal role in the transition to a low-carbon energy landscape.

Types of Geothermal Systems: Geothermal energy is harnessed through various systems, including hydrothermal, enhanced geothermal systems (EGS), and direct-use applications. Hydrothermal systems utilize naturally occurring reservoirs of hot water and steam found beneath the Earth's surface. EGS involve creating engineered reservoirs in hot rock formations where water can be circulated to generate steam. Direct-use applications involve utilizing geothermal heat for space heating, greenhouse cultivation, and industrial processes.

Geothermal Power Generation Process: The core of geothermal power generation involves tapping into the heat stored within the Earth's crust. Hot water or steam is extracted from geothermal reservoirs, and its energy is converted into electricity through steam turbines. The residual heat can be utilized for direct-use applications, contributing to energy efficiency and reducing emissions.

Advancements in Enhanced Geothermal Systems: Enhanced Geothermal Systems (EGS) have the

potential to expand geothermal energy generation to regions previously considered unsuitable. By injecting water into hot rock formations and creating permeable pathways, EGS enable the extraction of heat from deeper layers of the Earth's crust. Advances in drilling technology, reservoir engineering, and heat exchange mechanisms are driving the progress of EGS.

Environmental Considerations: Geothermal energy offers significant environmental benefits, such as low carbon emissions and minimal air pollution. However, improper management of geothermal fluids can result in the release of trace gases and minerals. Careful monitoring and mitigation strategies are essential to ensure the sustainability of geothermal operations and prevent any adverse environmental impacts.

Geothermal Energy's Reliability and Baseload Capacity: Geothermal power generation stands out for its reliability and consistent output, regardless of weather conditions. Its baseload capacity makes it a valuable complement to intermittent renewable sources like solar and wind, enhancing grid stability and security.

Challenges and Solutions: While geothermal energy holds promise, it is not devoid of challenges. Not all regions possess suitable geothermal resources, and drilling deep into the Earth's crust involves technical and financial complexities. Collaboration between the geothermal industry, governments, and research institutions is vital to address these challenges,

optimize exploration techniques, and advance geothermal technologies.

International Geothermal Cooperation: Geothermal energy has the potential to benefit regions around the world, and international cooperation plays a significant role in its advancement. Sharing knowledge, experiences, and best practices accelerates geothermal development, particularly in regions where resources are untapped.

Geothermal Energy for Heat Pumps: Beyond electricity generation, geothermal energy plays a role in space heating and cooling through heat pump systems. Ground-source heat pumps utilize the stable temperature of the Earth's subsurface to provide energy-efficient heating and cooling for buildings.

Future Outlook: The future of geothermal energy hinges on continued research, technological innovation, and collaborative efforts to unlock its full potential. Advancements in EGS technology, coupled with responsible resource management, have the potential to expand geothermal energy's footprint and contribute substantially to a sustainable energy mix.

In conclusion, geothermal energy offers a reliable, sustainable, and low-carbon option for power generation and direct-use applications. By harnessing Earth's natural heat, societies can contribute to a cleaner and more resilient energy future while addressing the challenges of climate change and energy security.

Biomass Energy:

Biomass Energy: Nurturing Sustainability through Organic Power Generation

Biomass energy, derived from organic materials such as agricultural residues, forest biomass, and organic waste, presents a versatile and renewable source of power. This section delves into the intricacies of biomass energy, exploring its various conversion technologies, environmental benefits, challenges, and its role in the broader context of a sustainable energy landscape.

Biomass Conversion Technologies: Biomass energy is generated through various conversion technologies, including combustion, gasification, pyrolysis, and anaerobic digestion. Combustion involves burning biomass to produce heat and electricity. Gasification and pyrolysis processes convert biomass into syngas and biochar, respectively, which can be further utilized for power generation, biofuels, or other applications. Anaerobic digestion breaks down organic matter to produce biogas, primarily composed of methane and carbon dioxide, which can be used for electricity generation and heat.

Benefits of Biomass Energy: Biomass energy offers several advantages, such as reducing reliance on fossil fuels, diverting organic waste from landfills, and promoting sustainable land management practices. It also contributes to rural economic development by creating jobs in agriculture, forestry, and the bioenergy sector.

Bioenergy and Waste Management: Biomass energy plays a significant role in waste management by utilizing organic waste streams that would otherwise contribute to landfill

emissions. The conversion of organic waste into energy not only reduces environmental impacts but also generates renewable power.

Environmental Considerations: While biomass energy is considered renewable, its environmental impact varies based on factors such as feedstock sourcing, land use, and emission control technologies. Sustainable biomass practices involve considering carbon neutrality, maintaining ecosystem health, and minimizing air pollutants from combustion.

Challenges and Sustainability: Biomass energy faces challenges related to feedstock availability, land competition, and potential impacts on food security. Balancing energy production with land use for agriculture and conservation is a complex issue that requires thoughtful planning and policy considerations.

Advanced Biomass Technologies: Advancements in biomass technology focus on improving conversion efficiencies, reducing emissions, and enhancing feedstock versatility. Second-generation biomass technologies, utilizing non-food feedstocks like agricultural residues and algae, hold the potential to overcome some challenges associated with first-generation feedstocks.

Biofuels and Transportation: Biomass energy extends to the transportation sector through the production of biofuels such as bioethanol and biodiesel. These renewable fuels offer alternatives to fossil fuels and help reduce carbon emissions in the transportation industry.

Local and Regional Impacts: The local and regional impacts of biomass energy projects are diverse. They can foster economic growth, improve waste management, and enhance energy security, but also require careful consideration of social and environmental implications.

Future Prospects: The future of biomass energy hinges on responsible resource management, technological innovations, and the integration of biomass with other renewable energy sources. Advancements in sustainable feedstock cultivation, efficient conversion technologies, and carbon capture techniques will shape the trajectory of biomass energy's role in the broader energy landscape.

In conclusion, biomass energy presents a multifaceted solution to both energy and waste management challenges. By capitalizing on organic materials that abound in various forms, societies can tap into a versatile and renewable energy source that contributes to a cleaner, more sustainable future while addressing waste management concerns.

CONCLUSION

Paving the Path to a Sustainable Energy Future through Renewable Sources

In a world grappling with the urgent need to address climate change and transition away from fossil fuels, renewable energy sources have emerged as beacons of hope, offering a cleaner, more sustainable path forward. This comprehensive exploration of solar, wind,

hydroelectric, geothermal, and biomass energy sources underscores their collective potential to reshape the global energy landscape.

Each renewable energy source brings its own unique set of advantages, challenges, and innovations. Solar energy, with its rapid technological advancements and versatile applications, is poised to become an increasingly significant contributor to electricity generation. Wind energy's evolution, from towering onshore turbines to expansive offshore farms, highlights its reliability and its role in enhancing energy security. Hydroelectric power generation continues to provide grid stability and baseload capacity, with modern advancements mitigating its environmental impacts. Geothermal energy taps into the Earth's natural heat reservoirs, offering a consistent and dependable power supply. Biomass energy, derived from organic materials, bridges energy generation with waste management, promising a more circular and sustainable approach.

The journey towards a renewable energy future is not without obstacles. Intermittency challenges, energy storage limitations, regulatory barriers, and environmental concerns must be addressed collaboratively. Technological innovations, policy frameworks, and international cooperation are crucial pillars that will propel the transition. By embracing smart grids, energy storage breakthroughs, and innovative materials, we can conquer the variability of renewable sources and ensure a reliable energy supply.



Moreover, a significant stride towards sustainable energy relies on the support of governments, industries, and local communities. Policy frameworks that incentivize renewable adoption, international agreements that commit to emission reduction goals, and grassroots efforts to promote awareness are vital components of the transformation.

As we look to the future, the momentum towards renewable energy adoption is encouraging. The ongoing research, innovation, and collaborations across these diverse energy sectors fuel optimism. By tapping into the power of the sun, wind, water, Earth's heat, and organic matter, societies can collectively forge a path towards a cleaner, greener, and more resilient energy future. Through diligent stewardship of these resources, we can mitigate climate change, enhance energy security, and create a sustainable legacy for generations to come.

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